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EXPERIENCE WITH AND IMPROVEMENTS IN CONTAINMENT VESSEL PENETRATIONS

by Charles W. Conant

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Cleveland, Ohio

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ABSTRACT

Early Plum Brook Reactor containment-vessel leak-rate tests showed that potted electrical penetrations were a major contributor to the containment-vessel leakage. This type of penetration has largely been replaced with hermetic penetrations. Leak-rate testing of the hermetic penetrations is done by the pressure decay method having a sensitivity better than 0.001 ft^3/day (2.8×10^{-5} m^3/day). The tests show that the average penetration leak rate is less than 0.003 ft^3/day (8.5×10^{-5} m^3/day). The use of hermetic penetrations has significantly reduced leakage through electrical penetrations, reduced maintenance, and reduced effort required to change cables penetrating the containment vessel.

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SUMMARY

Early containment-vessel leak-rate tests showed that potted electrical penetrations were a major contributor to the containment vessel leakage. This type of penetration has largely been replaced with hermetic penetrations. Leak-rate testing of the hermetic penetrations is done by the pressure decay method having a sensitivity better than 0.001 cubic foot per day (2.83×10^{-5} m^3/day). The tests show that the average penetration leak rate is less than 0.003 cubic foot per day (8.49×10^{-5} m^3/day).

INTRODUCTION

The NASA Lewis Plum Brook Reactor is a 60-megawatt (thermal) pressurized-water test reactor.

The reactor is in a 100-foot (30.48-m) diameter sealed steel containment vessel having a design pressure of 5 psig (3.45×10^4 N/m^2 gage). The free internal volume of the containment vessel is approximately 450 000 cubic feet (12 730 m^3). The allowable leak rate from the containment vessel is 450 cubic feet per day (12.73 m^3/day) at an over-pressure of 0.3 psig (2.07×10^3 N/m^2 gage). An integrated leak-rate test is performed every 2 years at a test pressure of 4 psig (2.76×10^4 N/m^2). The higher pressure is used to increase the sensitivity of the test and to reduce the test time. A linear extrapolation is used to relate the leak rate at 0.3 psig (2.07×10^3 N/m^2).

There are approximately 80 electrical penetrations and 110 pipe penetrations of the containment vessel. Most of the pipe penetrations are seal welded to the containment vessel. The exceptions to this are about 30 bulkhead fittings. Approximately 10 of the pipe penetrations are pipe sleeves having a blind flange on both ends.

The original potted electrical penetrations were a major contributor to the leakage of the containment vessel. This report describes the deficiences of the potted electrical penetrations and the evolution and results achieved with hermetically sealed electrical penetrations.

ORIGINAL ELECTRICAL PENETRATIONS

Early containment-vessel leak-rate tests showed that a major contributor to allowable containment vessel leakage was the electrical penetrations. A typical original penetration is shown in figure 1. Although this figure shows a single cable, most of the penetrations contained more than one. Some had as many as eight. This same type of penetration was used for power, control, and coaxial cables. This type of penetration has several deficiencies that have been noted in the literature (e.g., ref. 1):

(1) Leakage may occur between the cable sheath and the insulation on the individual conductors.

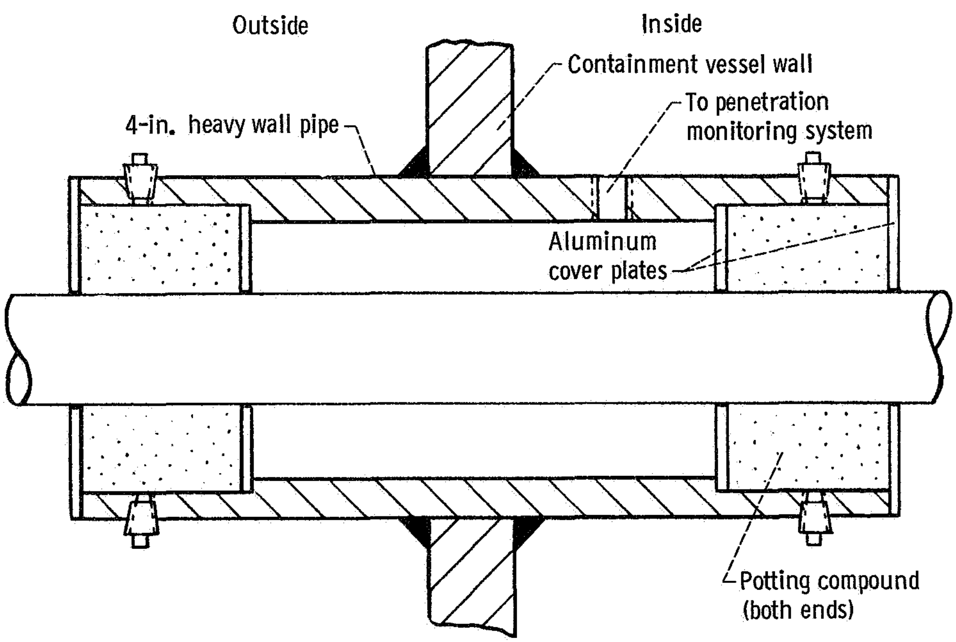

Figure 1. - Original electrical penetration.

(2) Leakage occurs between the conductor insulation and the conductor and between strands when stranded wire is used.

(3) Most potting compounds deteriorate with time and considerable effort was required to maintain the penetrations.

(4) Changing cables is quite time consuming. All the old potting must be removed and new cover plates must be made to match the new cables.

Recognizing the deficiencies in the original penetrations, the Plum Brook Reactor staff set out to investigate better methods of making electrical penetrations.

NEW ELECTRICAL PENETRATIONS

Three different types of electrical penetrations were required: power, control, and coaxial cable penetrations. The results of our investigation for each of these types will be discussed separately.

Power Penetrations

The first revised power penetration consisted of a stainless-steel flange containing three spark-plug type connectors. These spark-plug connectors had a current-carrying capacity of 300 amperes. The leakage was not excessive. However, in order to leak test this penetration, it was necessary to disconnect and reconnect the cables on one side of the penetration. This not only required considerable manpower and interruption of the electrical service, but handling the relatively stiff, high capacity cables caused breakage of the porcelain insulators. This penetration was therefore removed and replaced with the type of penetration shown in figure 2.

Three conductors pass through each penetration to accommodate three-phase power feeds. To avoid hysteresis heating, the plate must be nonmagnetic. The two seals on each conductor are called electrical conductor sealing glands. They have a flourine plastic insulator and seal. These glands come in a variety of sizes with ratings up to 400 amperes and 16 000 volts. Prior to installation, these glands were bench tested to determine the leak rate. The measured leak rate of a single gland was less than 5×10^{4} cubic foot per day (1.4×10^{-5} m^3/day) at a pressure differential of approximately 4 psi (2.76×10^{4} N/m^2).

This penetration has a double seal. It can therefore be monitored and leak-rate tested without disconnecting the cables. In practice, the space between the seals is continuously monitored by a Penetration Monitoring System, and no individual leak tests are run on these penetrations.

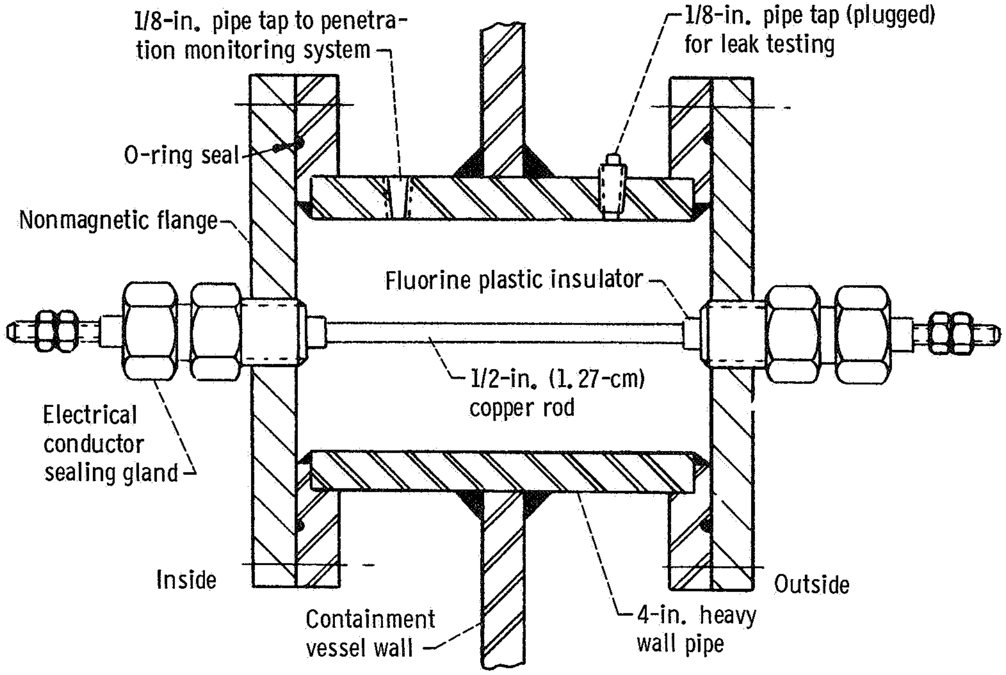

Figure 2. - Power penetration.

Control Cable Penetrations

Control cables were a larger source of leakage than the power cables in the original installation, primarily because there were more of them.

Most of the original (potted) control penetrations have now been replaced by glass sealed hermetic connectors welded into a stainless-steel (nonmagnetic) plate. These connectors have an advertised leak rate of 3.2×10^{-5} cubic foot per day (9.1×10^{-7} m^3/day) at 1 atmosphere pressure differential. Several of these were tested on a mass spectrometer leak detector and were found to be considerably better than this.

The pressure rating on these connectors is not known. However, it has been used in another application where it survived a 270-psig (1.86×10^{6}-N/m^2) pressure test without damage.

Some experimentation was required to determine the best way to fasten the connectors to the plate. The first attempt consisted of soft soldering the connectors into a brass plate with a close tolerance fit. Since several connectors were being placed in each plate, the soldering had to be done in an oven in order to solder all connectors at once. Even then, it was difficult to get a leak-tight joint on all connectors. Further-

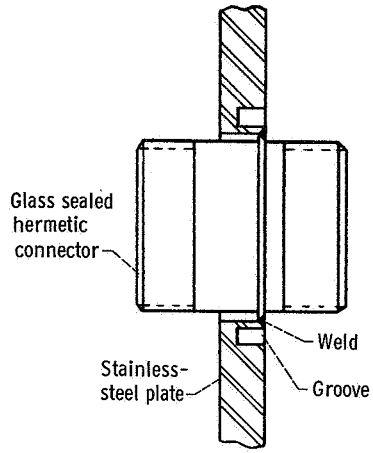

Figure 3. - Hermetic control cable penetration.

more, the slight flexing of the plate, caused by pressure differential during testing, could cause a soldered joint to leak.

Therefore, the method of mounting the connector shown in figure 3 was used. The square connector flange is first turned round and then tungsten-inert-gas welded into the stainless-steel plate. It was necessary to turn the groove into the plate to avoid drawing as the weld cooled. This drawing sometimes caused cracking of the glass seals.

One of this type of mounting was tested to determine the force necessary to break the seal. The weld was expected to be the weakest point; however, failure occurred at about 5500 pounds (2.45×10^4 N) at the point where the connector flange attached to the body of the connector. This compares with 2400 to 3600 pounds (1.07×10^4 to 1.6×10^4 N) for the soldered type.

The method of mounting the penetration plate into the containment vessel is shown in figure 4. There are nine connectors in each assembly, and each connector has 37 pins. There are 18 such assemblies now in use. Therefore, approximately 6000 single wire penetrations are available. The leak rate on this type of assembly measured in place by the differential pressure method (discussed later) is generally less than 0.005 cubic foot per day (1.4×10^{-4} m^3/day) including the connectors, the weld, and the O-ring seal.

This type of installation is costly, but the excellent leak rates obtained, the ease of changing conductors, and the reduction of maintenance make it well worth the cost. The connectors cost about $50 each, and the cost of machining the plate and connector flanges and the welding bring the total cost per plate to about $750. This does not include the cost of the pipe sleeve in the containment vessel wall.

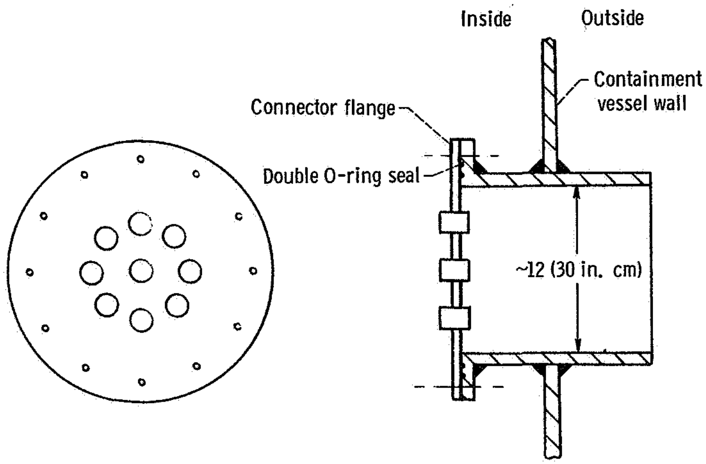

Figure 4. - Control cable penetration assembly.

Coaxial Cable Penetrations

In designing the coaxial-cable penetrations, a restriction was imposed that the shield on the cable could not be grounded at the connector. This meant that a connector electrically equivalent to a triaxial connector was needed. No commercially available, hermetically sealed connector of this type could be found. Therefore, the method of mounting shown in figure 5 was devised. Type HN pressure bulkhead fittings (MIL number UG 1019/U) are used. These connectors have a fluorine plastic insulator-seal. The connector, which is made for a gasketed seal, was modified slightly as shown in figure 5. The phenolic resin slug is a standard metallographic specimen mount that has been drilled and threaded inside and out. On assembly, epoxy potting compound is painted on all the threaded joints and over the exposed surfaces of the Bakelite. Thus, the threads provide the necessary mechanical strength to the assembly and the epoxy provides the seal. Nineteen of these connectors are mounted in a 1/2-inch (1.27-cm) thick aluminum plate and the plate is mounted as shown in figure 4.

Again the maximum allowable pressure differential on these connectors is unknown. Although they will probably not withstand as high a pressure as the glass-sealed connectors, tests show them to be very good with a 5-psi (3.45×10^4-N/m^2) pressure differential. The leak rate for these penetrations is comparable to that of the control cable penetrations.

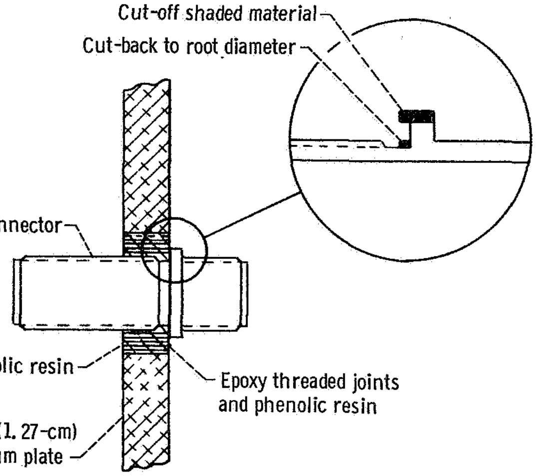

Figure 5. - Hermetic coaxial cable penetration.

PENETRATION LEAK-RATE TESTING

Frequent periodic in place leak-rate tests of the hermetic penetrations were performed to verify their continued serviceability. To obtain Atomic Energy Commission approval we agreed to insure that the leak rate of each unmonitored penetration must not contribute significantly to the overall containment vessel leak rate. This was arbitrarily defined as a leak rate limit of 0.1 cubic foot per day (2.83×10^{-3} m^3/day) on each penetration assembly and a total, for all 20 cubic feet per assemblies, of 1.0 cubic foot per day (2.83×10^{-2} m^3/day), both with a 4-psi (2.76×10^4-N/m^2) pressure differential. Each unmonitored penetration is now tested once each calendar year.

Originally, the leak-rate testing was done with a halogen leak detector. Leaks could easily be detected with this device. However, precise quantitative leak-rate information is difficult to obtain. Therefore the pressure-decay method was adopted. A schematic and photograph of the test setup are shown in figures 6 and 7, respectively.

The method of calculation for the pressure decay method follows. This method is somewhat different from those used in containment-vessel leak-rate calculations. The method is considerably simpler. However, the uncertainty calculations show that it is adequate for present purposes. (For containment-vessel leak-rate calculations see refs. 1 and 2.)

The leak rate is defined as

$$L = \frac{\Delta V}{t}$$

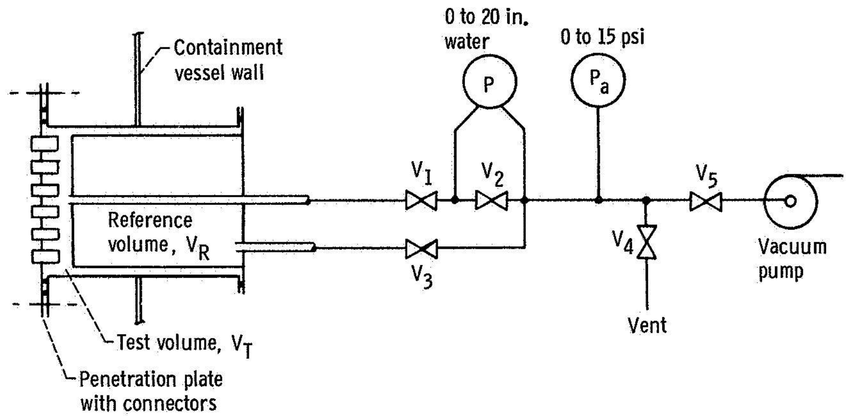

Figure 6. - Leak test apparatus.

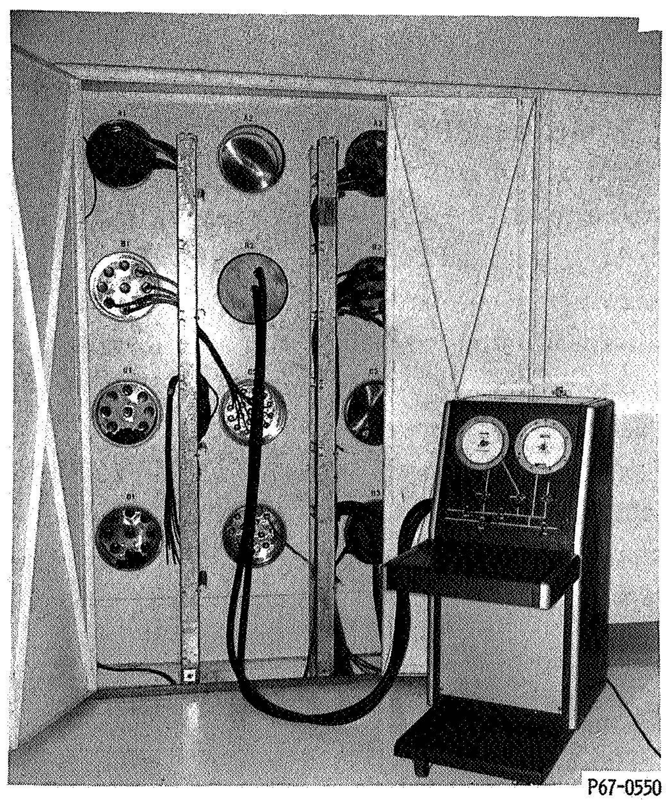

Figure 7. - Penetration cabinet with leak-test apparatus installed.

where

L leak rate, ft^3/day; m^3/day

ΔV change in volume, ft^3; m^3

t time, days

Now the standard volume of gas within a container at any pressure and temperature is

$$V_1 = V_c \frac{T_s}{P_s} \frac{P_1}{T_1}$$

where

V_1 standard volume of gas, ft^3; m^3

V_c volume of container, ft^3; m^3

T_s standard temperature, ^oR; K

P_s standard pressure, lb/ft^2; N/m^2

T_1 gas temperature, ^oR; K

P_1 gas pressure, lb/ft^2; N/m^2

If a small amount of gas is now introduced so that the new P and T are P_2 and T_2, the new volume of gas within the container will be

$$V_2 = V_c \frac{T_s}{P_s} \frac{P_2}{T_2} \text{ (standard ft}^3 \text{ or m}^3\text{)}$$

Then the volume of gas introduced is

$$\Delta V = V_2 - V_1 = V_c \frac{T_s}{P_s} \left[\frac{P_2}{T_2} - \frac{P_1}{T_1}\right]$$

Now, if $T_2 = T_1$, which is valid in this case,

$$\Delta V = V_c \frac{T_s}{P_s} \frac{(P_2 - P_1)}{T_1} = V_c \frac{T_s}{P_s} \frac{\Delta P}{T_1}$$

and

$$L = \frac{\Delta V}{t} = V_c \frac{T_s}{P_s} \frac{\Delta P}{T_1} \times \frac{1}{t}$$

Measurements were made to show that the test temperature does not change measurably during the test if one waits about 10 minutes after establishing the test pressure. Another inaccuracy that must be considered is a change in temperature of the reference volume relative to the test volume. A 1 R^{o} (0.6 K) temperature difference would appear as a ΔP of about 3/4 inch H_2O (187 N/m^2). This is equivalent to a leak rate of about 0.01 cubic feet per day (2.8×10^{-4} m^3/day). Since the test volume surrounds the reference volume (see fig. 6) it is highly unlikely that a 1^{o} (0.6) temperature difference would occur under ordinary conditions.

The sensitivity of the system is dependent on the ability to measure small pressure differences and, hence, on the sensitivity of the differential pressure measuring device. Sensitivity can also be increased by making the test volume small so that a small leak will cause a relatively large change in pressure. Sensitivity can also be increased by lengthening the test time.

The accuracy of the system is dependent on several factors:

(1) Accuracy of knowledge of test volume

(2) Accuracy of ΔP measurement

(3) Accuracy of temperature measurement

(4) Accuracy of time of test

(5) Assumption that reference volume pressure does not change over test duration

(6) Assumption that temperature does not change over test duration

The sensitivity of the system is better than 0.001 cubic foot per day (2.8×10^{-5} m^3/day) with a 5-psi (3.45×10^{4}-N/m^2) pressure differential. The uncertainty in the leak rate is dependent on the leak rate. For a leak rate of 0.1 cubic foot per day (2.8×10^{-3} m^3/day), the uncertainty is less than 0.01 cubic foot per day (2.8×10^{-4} m^3/day). For lower leak rates, the absolute value of the uncertainty is less, but the percent uncertainty is higher. For example, the uncertainty in a leak rate of 0.01 cubic foot per day (2.8×10^{-4} m^3/day) is approximately 0.002 cubic foot per day (5.6×10^{-5} m^3/day).

Greater sensitivity and lower uncertainty could be obtained. However, for these purposes, it is not deemed necessary.

TEST PROCEDURE

A typical test is run as follows:

(1) The system is evacuated to about 9 psia (6.3×10^{4} N/m^2) and V_5 is then closed.

(2) The system is allowed to sit for about 10 minutes, and V_2 is then closed. Any pressure rise in V_T will then be indicated on the ΔP gage.

(3) The ΔP is then recorded after 10, 20, and 30 minutes. At this time, the test assembly is moved to another penetration.

The 10-minute wait in step (2) is to allow for temperature stabilization. The apparent leak rate is much higher immediately after the system is pumped down than it is after 10 minutes. This is due to the temperature reduction which results from the expansion during the pumpdown. Apparently, the temperature equalization rate is not the same for V_R and V_T.

CONCLUSIONS

The new power penetrations have been in service for about $1\frac{1}{2}$ years. These penetrations are connected to the penetration monitoring system; therefore, no measurements of the leak rate of individual penetrations are made. However, the penetration monitoring system records show that the leak rate is not excessive.

The new control and coaxial-cable penetrations have been in service for about $3\frac{1}{2}$ years. The largest leak rate ever measured with the pressure-decay apparatus on an installed penetration is less than 0.01 cubic foot per day (2.8×10^{-4} m^3/day). The average leak rate of the 20 penetrations is less than 0.003 cubic foot per day (8.5×10^{-5} m^3/day).

The installation of the hermetic penetrations has (1) significantly reduced the leakage through electrical penetrations, (2) reduced maintenance on electrical penetrations, and (3) considerably reduced the effort involved in changing cables that penetrate the containment vessel.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 21, 1968,
122-29-08-02-22.

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